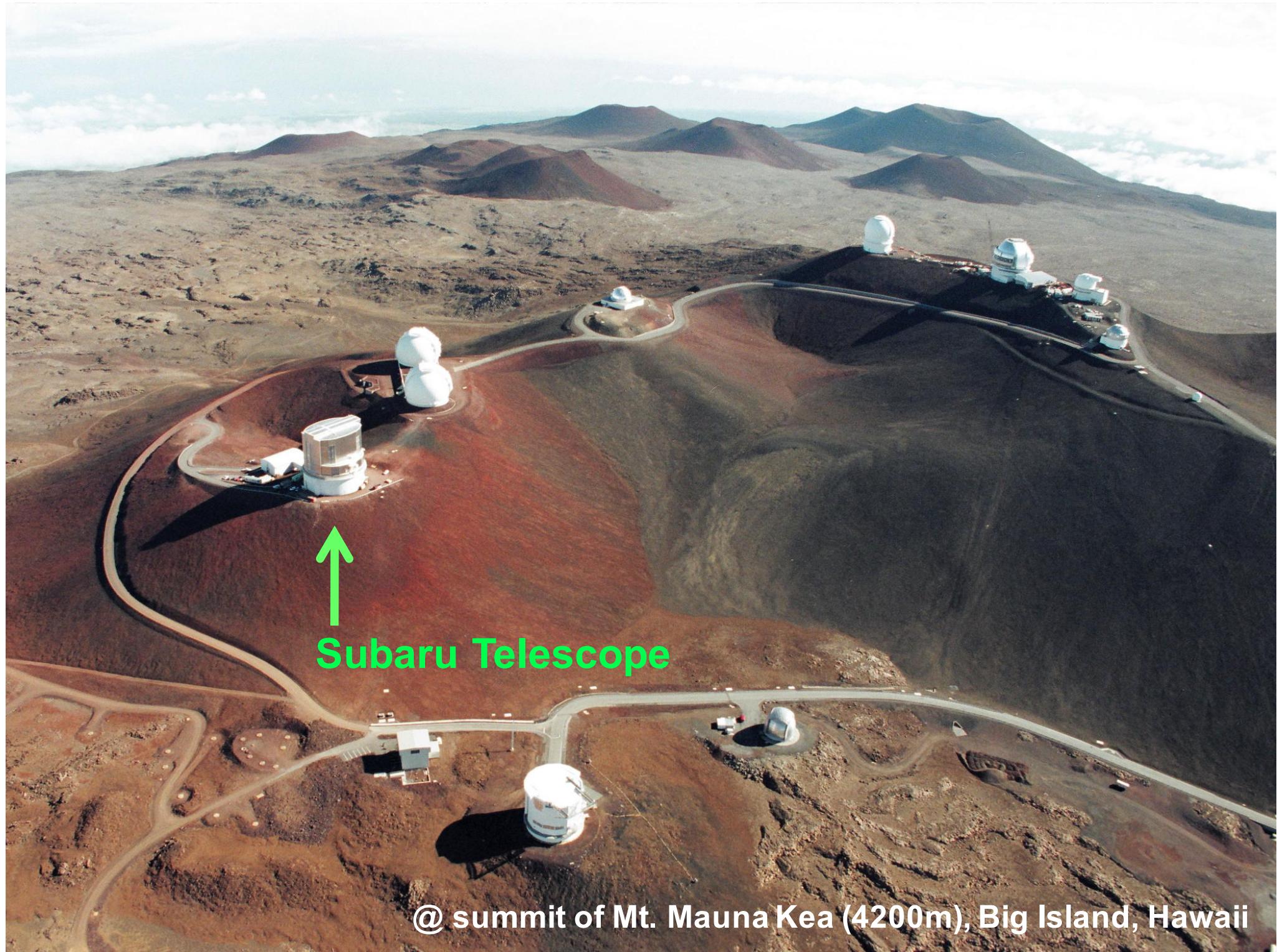


# SuMIRe: Subaru imaging and spectroscopic galaxy surveys

Masahiro Takada  
(Kavli IPMU, U. Tokyo)



@ BNL/Stony Brook , May 2016



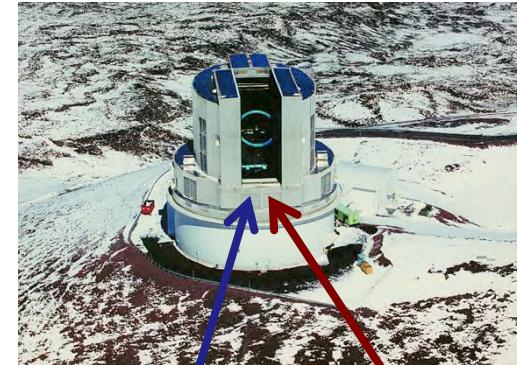
@ summit of Mt. Mauna Kea (4200m), Big Island, Hawaii



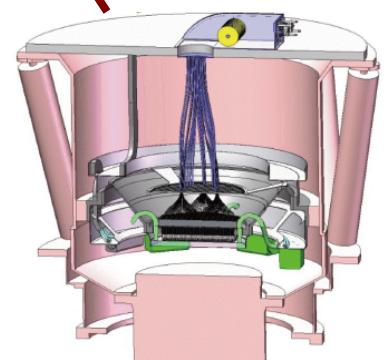
# SuMIRe = Subaru Measurement of Images and Redshifts

H. Murayama (Kavli IPMU Director)

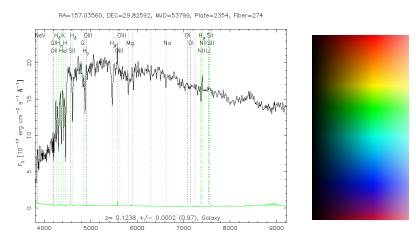
- Build *wide-field* camera (Hyper Suprime-Cam: ~\$55M) and *wide-field* multi-object spectrograph (Prime Focus Spectrograph: ~\$80M) for the Subaru Telescope (8.2m)
- Explore the fate of our Universe: dark matter, dark energy
- Keep the Subaru Telescope a world-leading telescope in the Thirty Meter Telescope era
- Precise images of I<sub>B</sub> galaxies
- Measure distances of ~4M galaxies
- **Do SDSS-like survey at z>1**



HSC



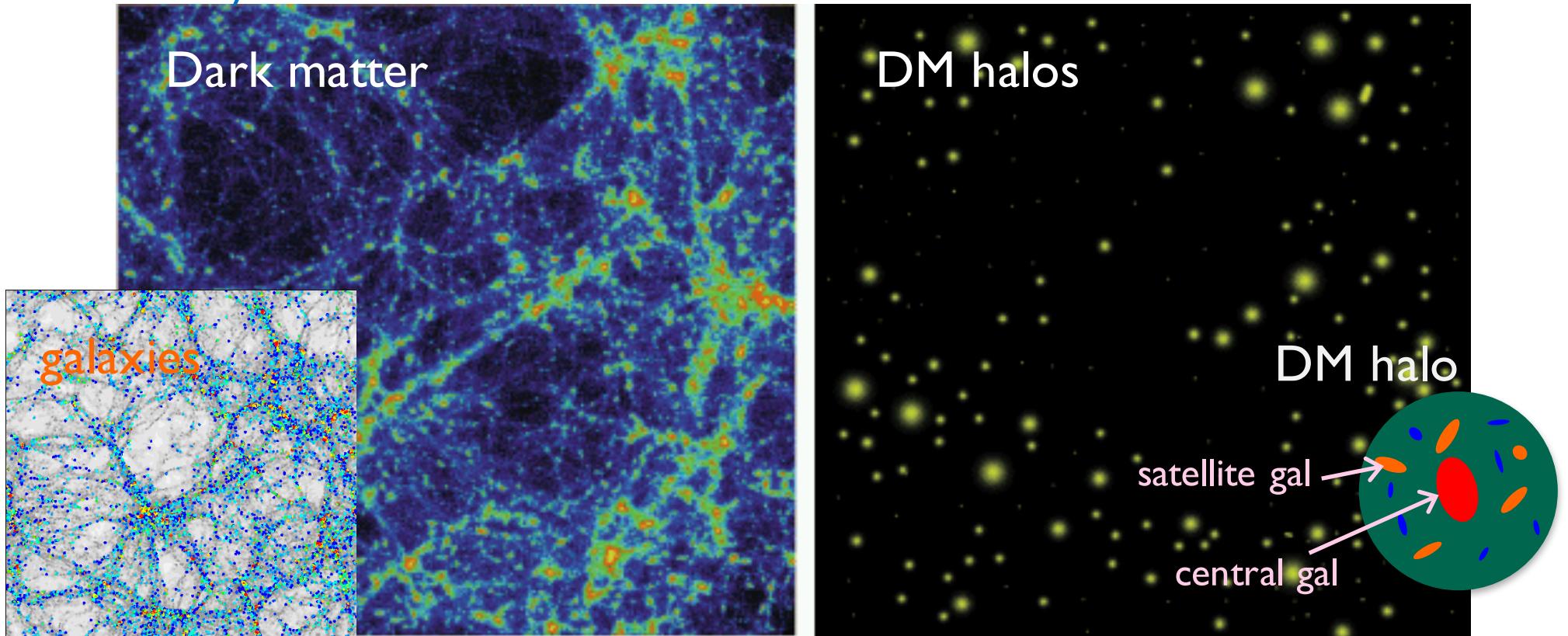
PFS



# Challenges: Galaxy Bias

*galaxy-halo connection*

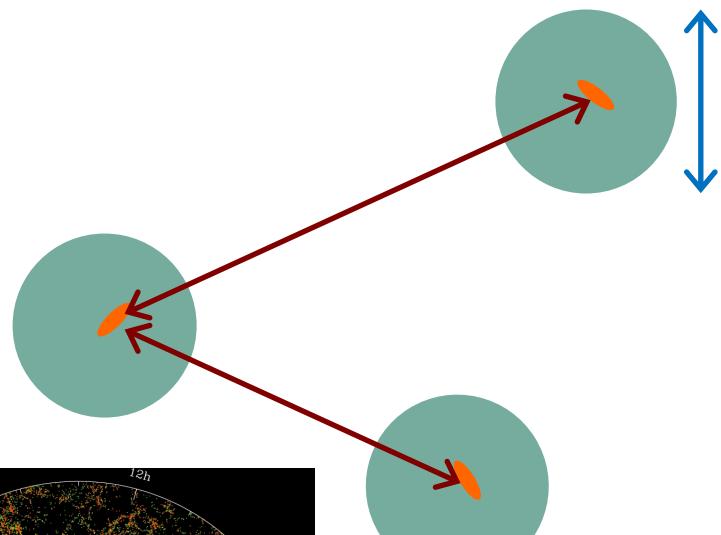
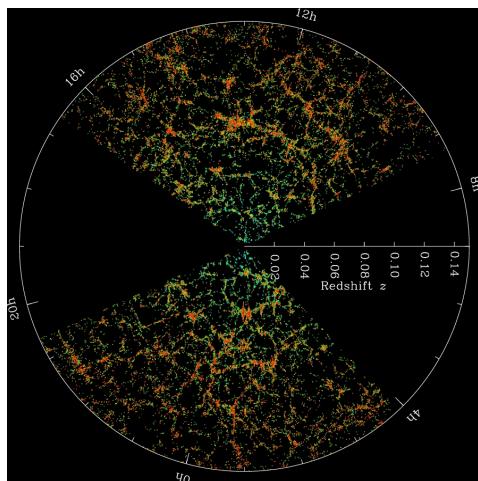
Cooray & Sheth 2002



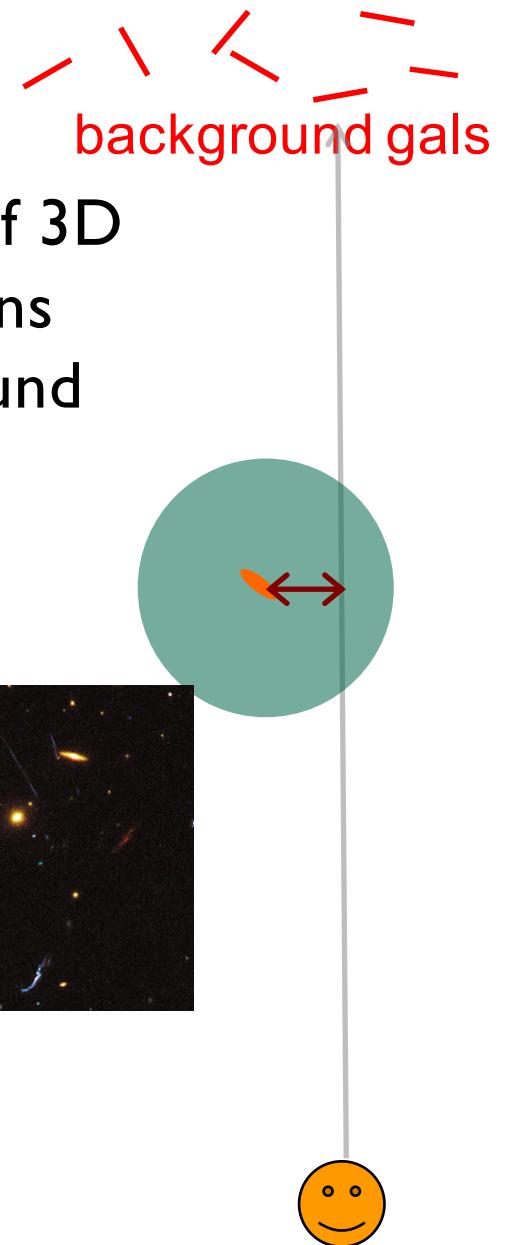
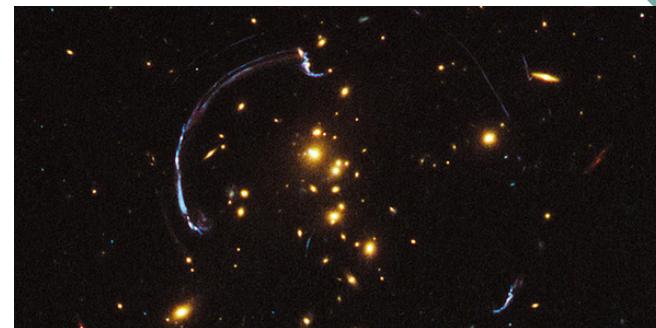
- Still impossible to accurately model galaxy formation from first principles
- Galaxies reside in dark matter halos
- Clustering of dark matter halos are relatively easy to model based on simulations and/or analytical models

# Combined probes: Clustering + Lensing

- Clustering analysis (3D galaxy distribution)
- Redshift-space distortion (**RSD**)



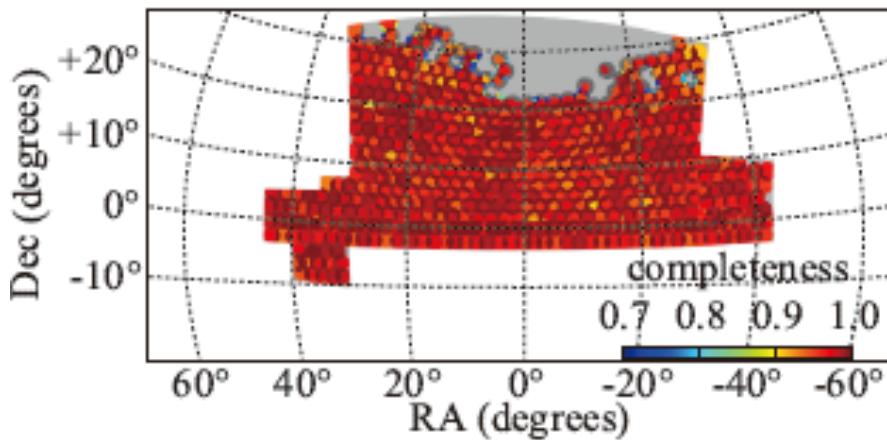
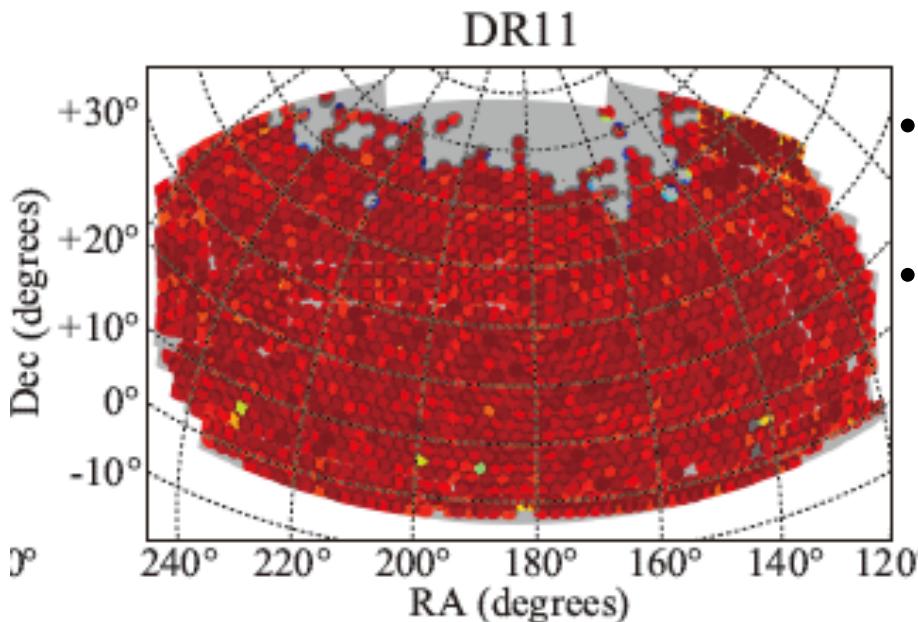
- Correlation of 3D galaxy positions with background galaxy **shapes**



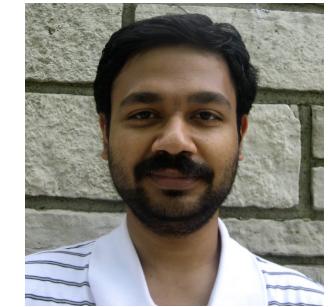
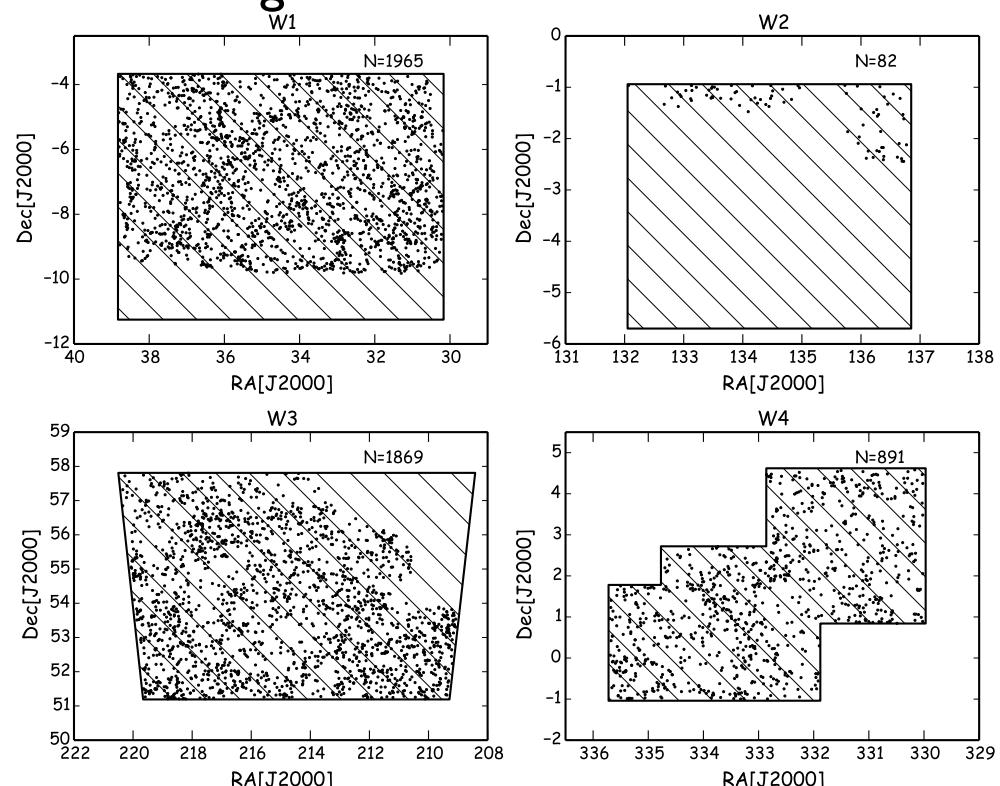
# Cosmology with lensing and clustering

*Miyatake, More*, Mandelbaum, MT, Spergel+15

*More, Miyatake*+15



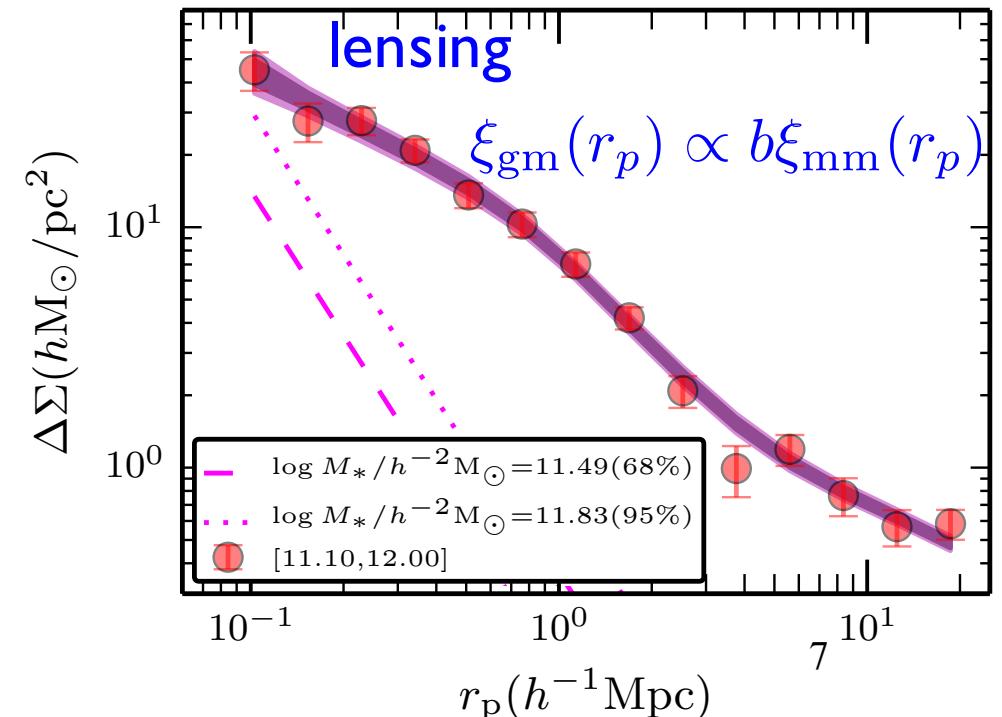
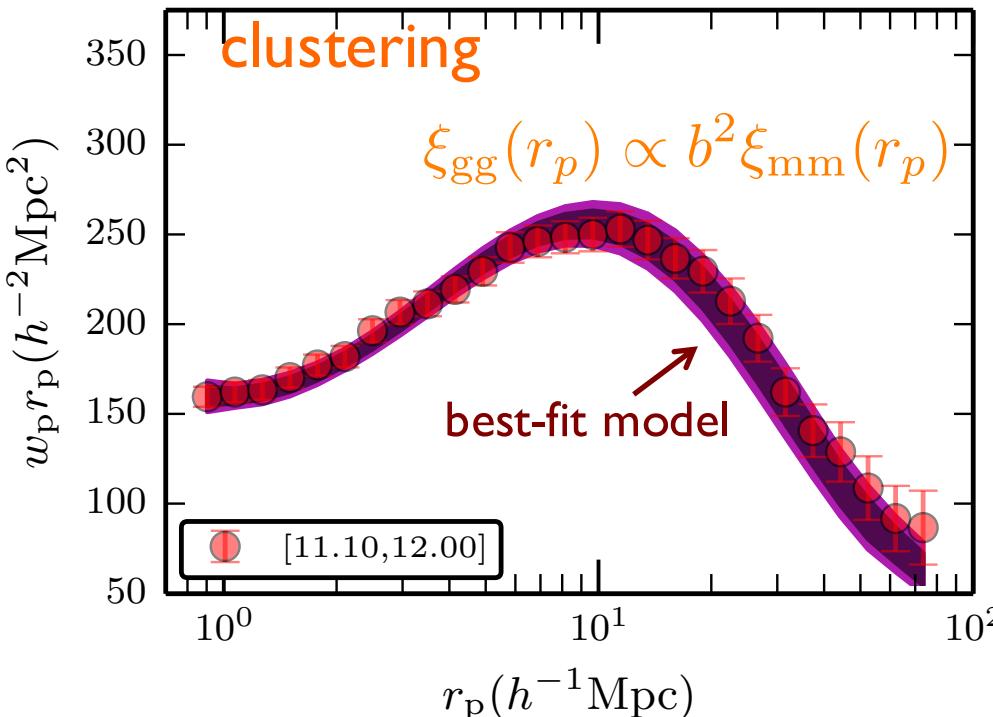
- BOSS DR11: ~0.8M CMASS gals ( $f_{\text{sky}} \sim 0.25$ ), and the lensing studies not yet done
- CFHTLenS: the overlapping region is ~120 sq. degs, ~4800 CMASS gals,  $\langle z_s \rangle \sim 0.7$
- Also Hikage+13



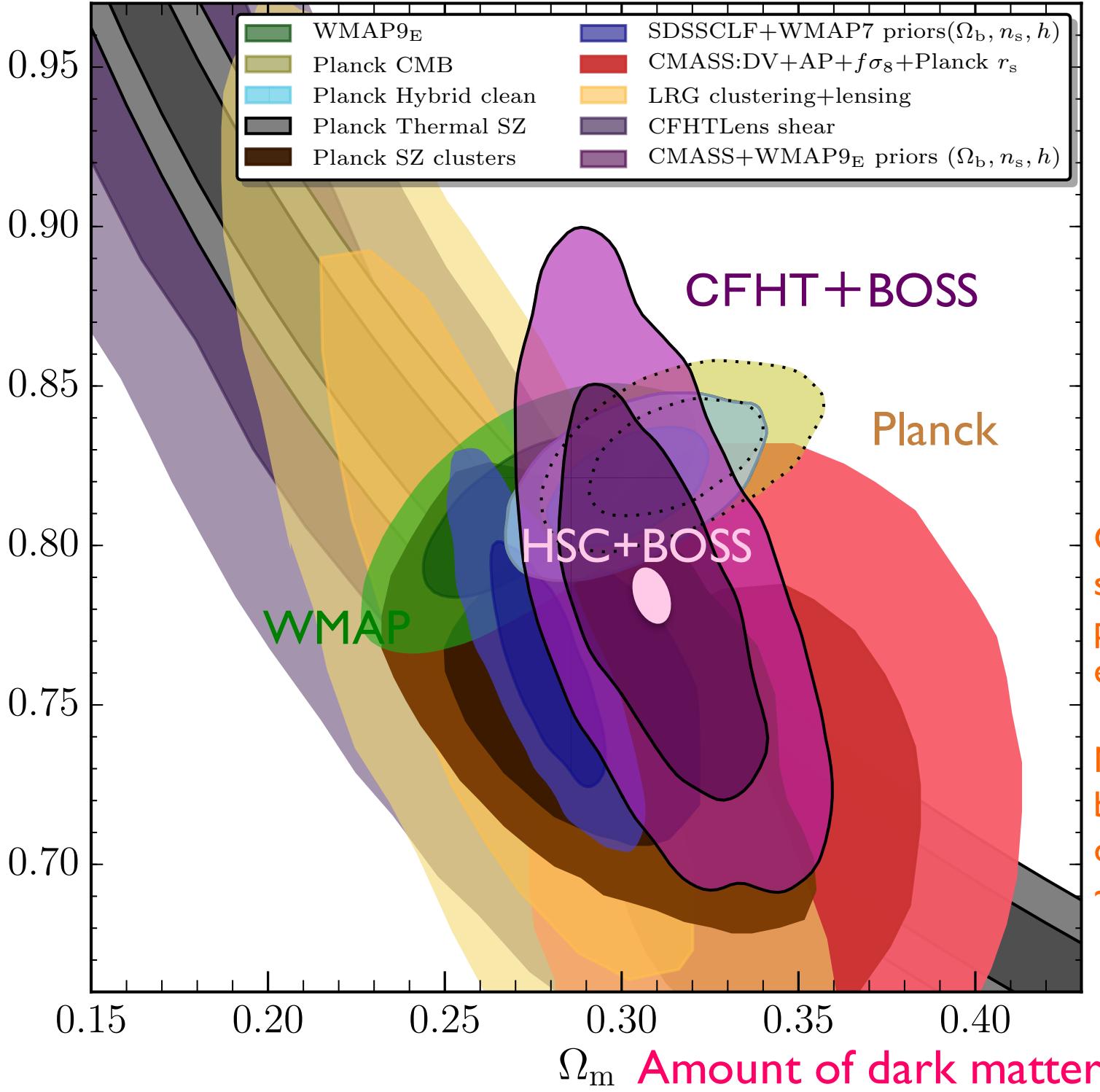
Hironao Miyatake   Surhud More

# Cosmology with lensing and clustering (cont'd)

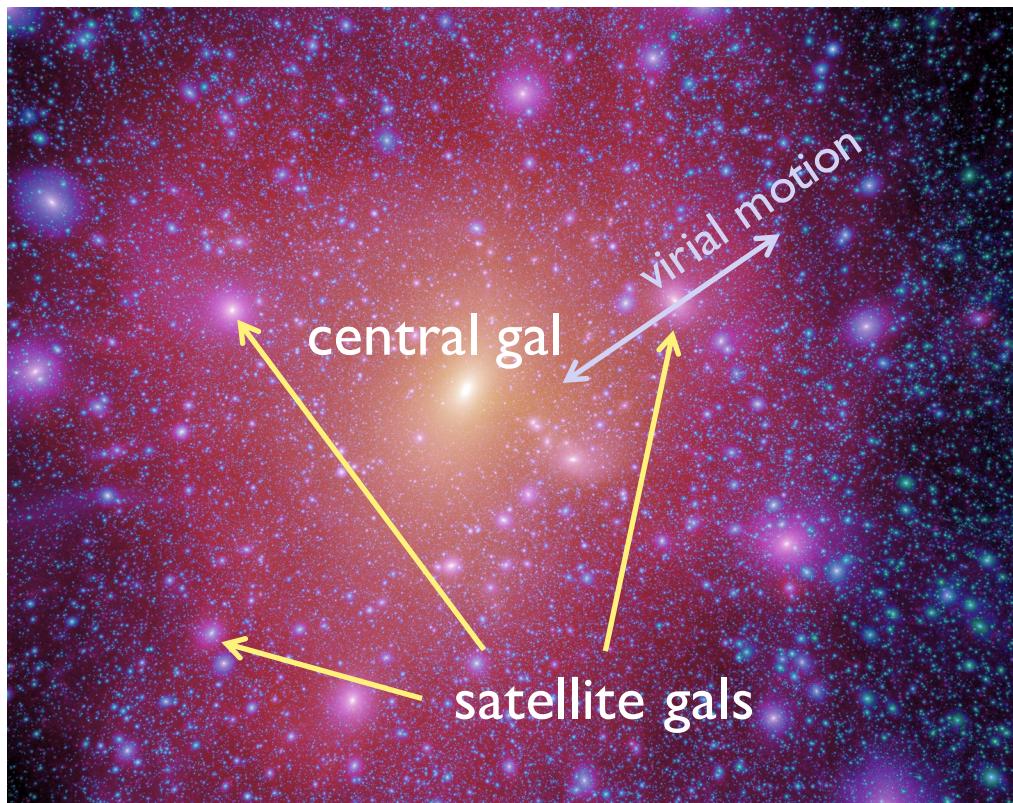
- Lensing: directly measure the DM distribution (but projected)
- Clustering: 3D mapping of galaxy distribution; a much higher S/N, but galaxy bias uncertainty
- CFHTLenS (3.6m imaging, *only  $\sim 100$  sq. deg,  $n_g(z>0.5) \sim 8 \text{ arcmin}^{-2}$* ) + BOSS (2.5m spec-z, 8,400 sq. deg,  $0.47 < z < 0.59$ )
- The model based on  $\Lambda$ CDM is in nice agreement with the measurements



The extent of dark matter spatial inhomogeneities

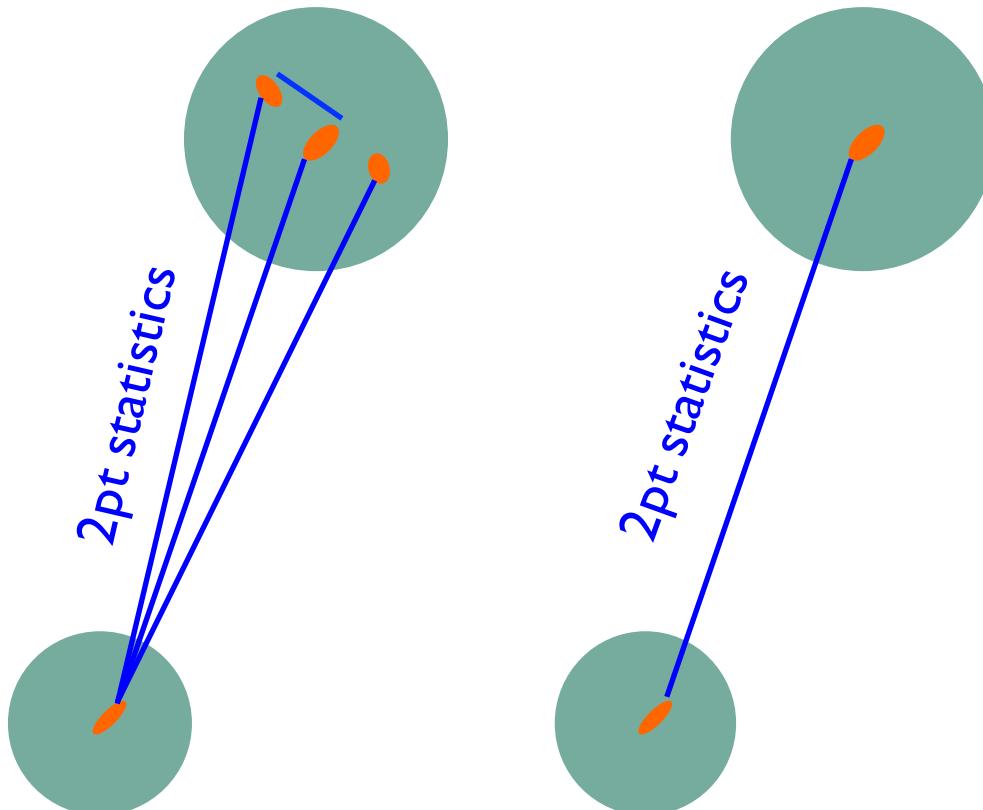


# galaxy = subhalo: central vs. satellite



- Galaxies = Sub-halos
- No clear boundary of a halo (a few Mpc at most)
- Central galaxy is in central subhalo (can be off-centered from the center of mass)
- Satellite galaxy(ies): more massive halo tend to have more satellite galaxies (e.g. abundance matching method)
- Satellite galaxies have internal virial motions = FoG effect (virial motion is larger in a more massive halo)

# Satellite galaxies useful for cosmology?



- 2pt correlation of galaxies
- If we have satellite galaxies in the sample, ...
  - More massive halos counted multiple times (more massive halos are more “biased” tracers)
  - I-halo term at small scales (more affected by baryon)
  - Need to know how to populate galaxies in halos: HOD...

$$P_{\text{gg}}^{\text{1h}}(k) = \frac{1}{\bar{n}_g^2} \int dM n(M) \langle N_g(N_g - 1) \rangle(M) |u_g(k; M)|^2$$

$$P_{\text{gg}}^{\text{2h}}(k) = \frac{1}{\bar{n}_g^2} \sum_{M, M'} w(M; k) w(M'; k) P_{\text{hh}}(k; M, M')$$

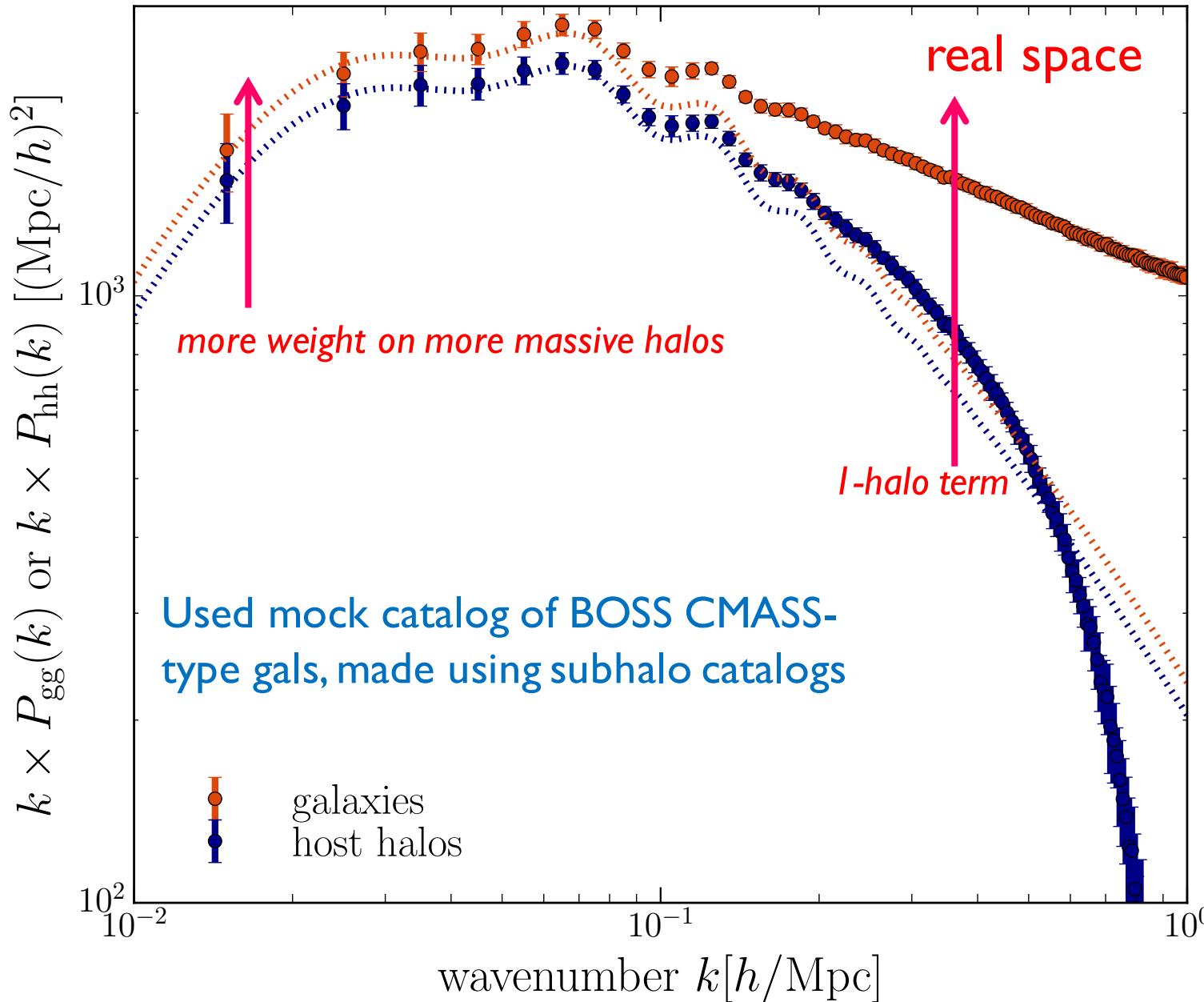
cosmology

# Halos vs. Galaxies

Okumura, MT, + in prep.

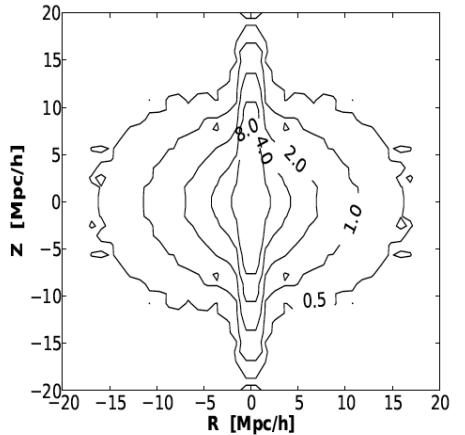
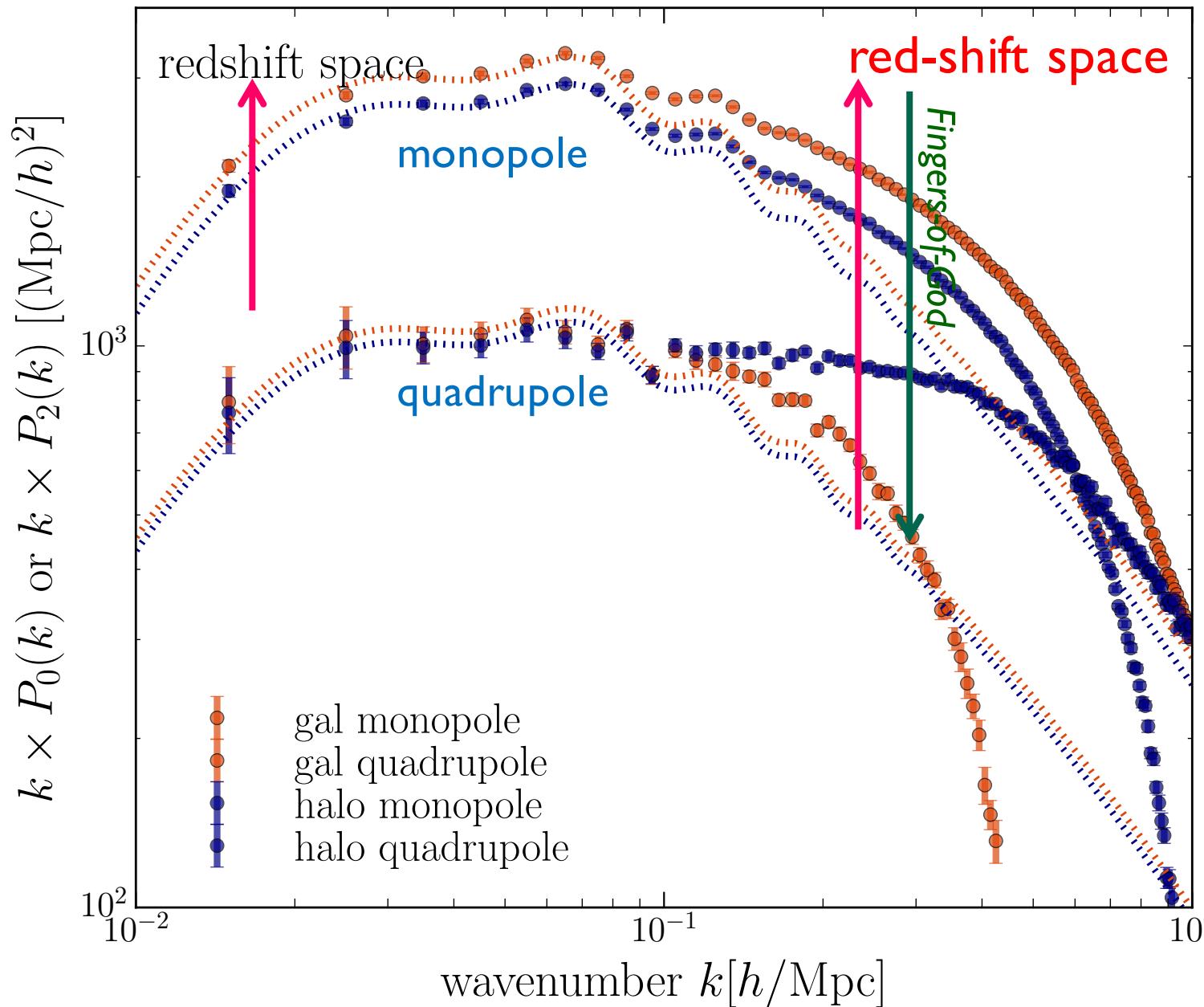


Teppei Okumura (IPMU)



# Halos vs. Galaxies

Okumura, MT, + in prep.



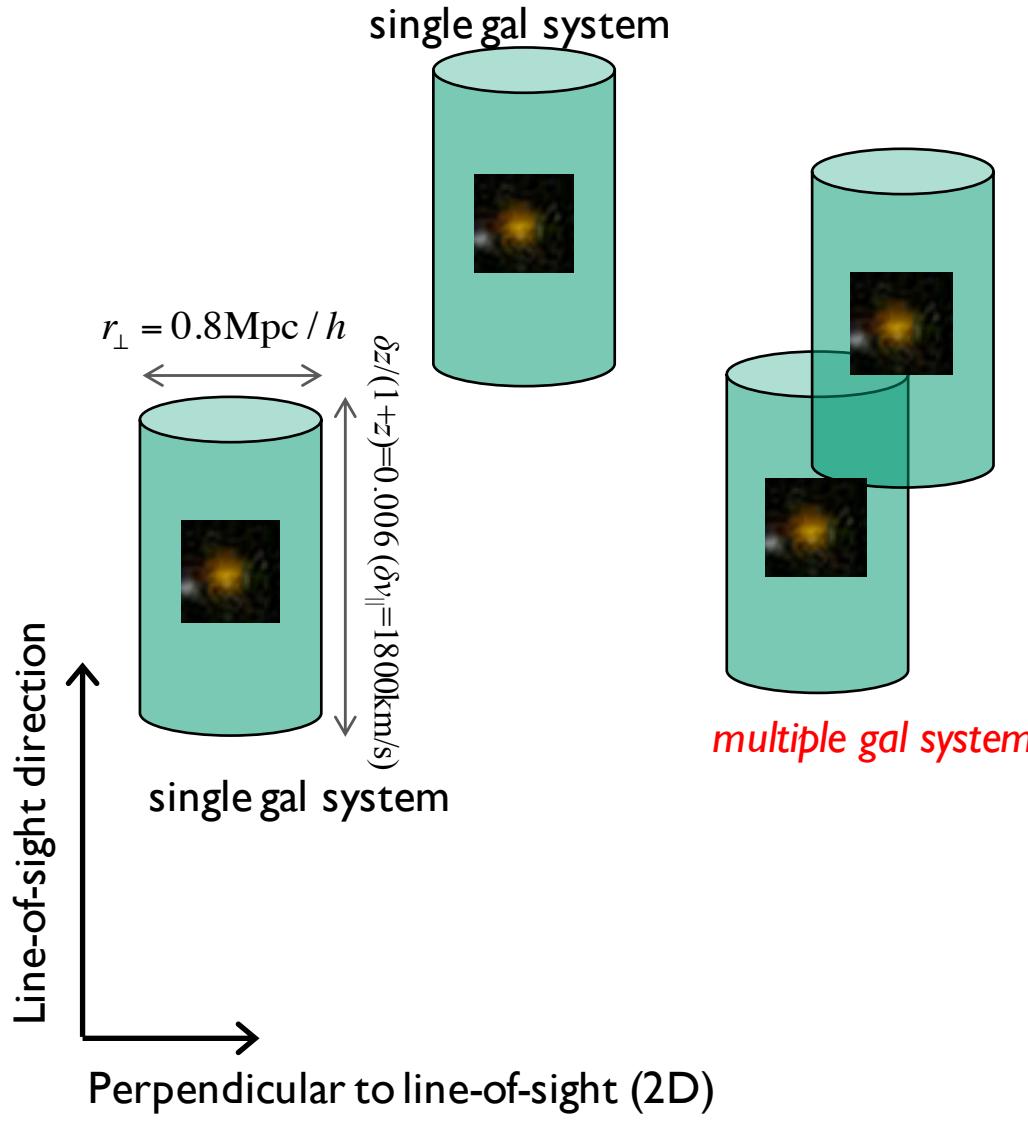
In redshift, further  
Fingers-of-God effect  
→ suppression

2pt correlation  
function of galaxies is  
different from that of  
halos over **all the**  
**scales** and in  
**monopole and**  
**quadrupole**

*A bad news*

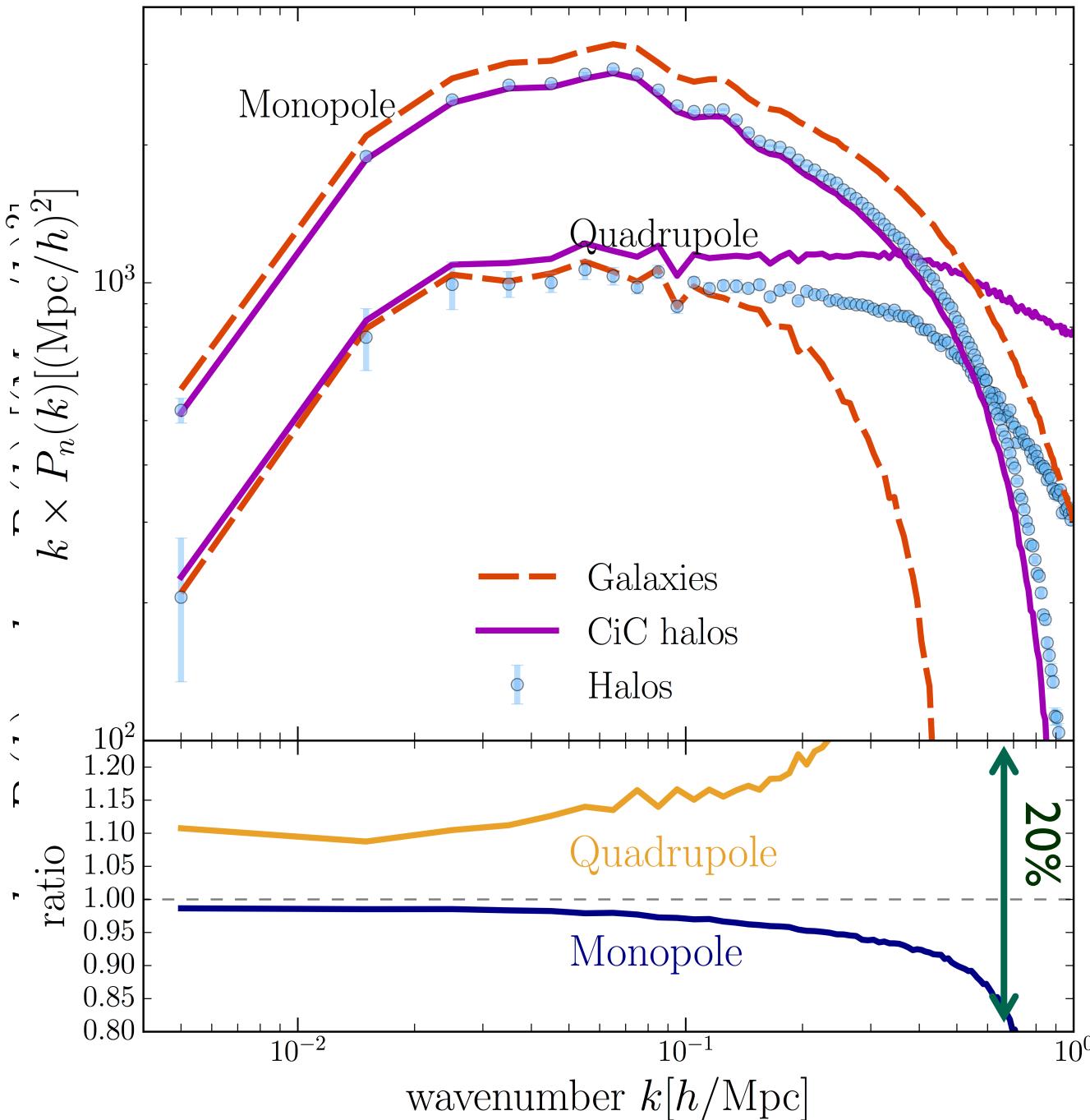
# From galaxies to halos: Counts-in-Cylinders FoF

Reid & Spergel 2009,  
Reid et al. 2010  
Hikage, Mandelbaum, MT+ 13



- Cylinder takes into account **RSD** due to peculiar velocity of galaxies
- **Isolated CiC = single galaxy system** (one gal in an isolated halo)
- **Grouping overlapping CiCs into “one halo”** just like N-body FoF = **multiple gal system** (cen. + sat.)
- SDSS LRGs: multiple systems  $\sim 5\%$
- SDSS CMASS:  $\sim 10\%$
- Filter out effects from the same halo (baryonic physics, I-halo term)
- Less affected by “fiber collision”
- Note: off-centering effect

# CIC-halo power spectrum



Okumura, MT, + in prep.

- Better than galaxies, but it didn't work
- Systematic difference (~20% for this type of gals)  
Why?  
We needed 2yrs to figure out



LRG ( $z=0.334$ )

270  $\text{kpc}/\text{h}$

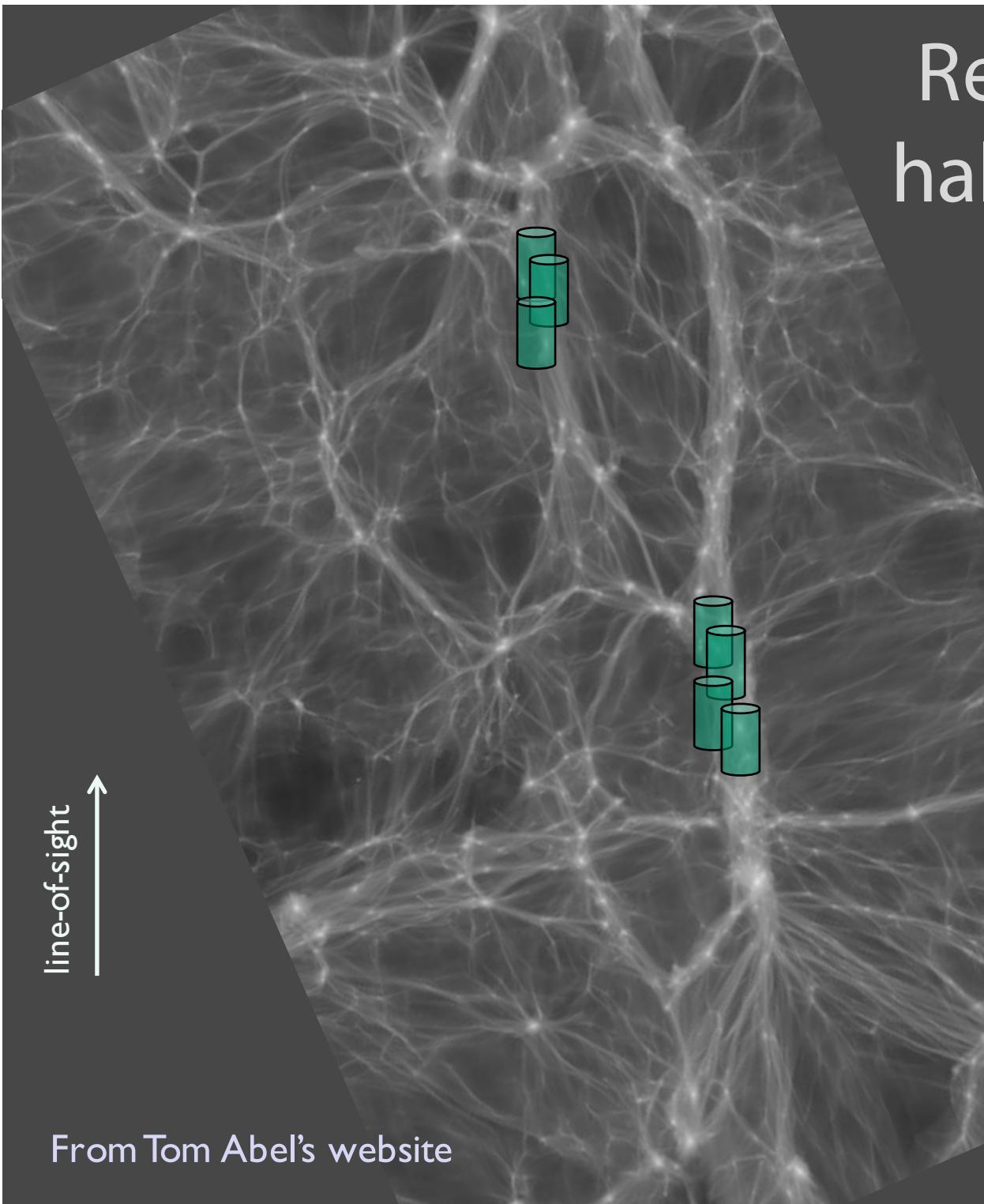
LRG ( $z=0.329$ )  
LRG ( $z=0.332$ )

Image © 2007 DSS Consortium  
Image © 2007 SDSS

Google earth

# Refinement of CiC halo reconstruction

- CiC window (cylinder) is anisotropic in redshift space
- Misidentification of multiple halos into “the same CiC halo” tends to happen in LSS filaments along line-of-sight (but large scales)
- Even if applying CiC method to real-space gal distribution, it causes artificial RSD



From Tom Abel's website

# Refinement of CiC halo power spectrum

Okumura, MT, + in prep.

- Need to correct for the exclusion effect due to CiC cylinder (e.g. Baldauf et al. 2013)
- Need to correct for “apparent” (artificial) RSD due to “large-scale clustering” of misidentified CiC halos

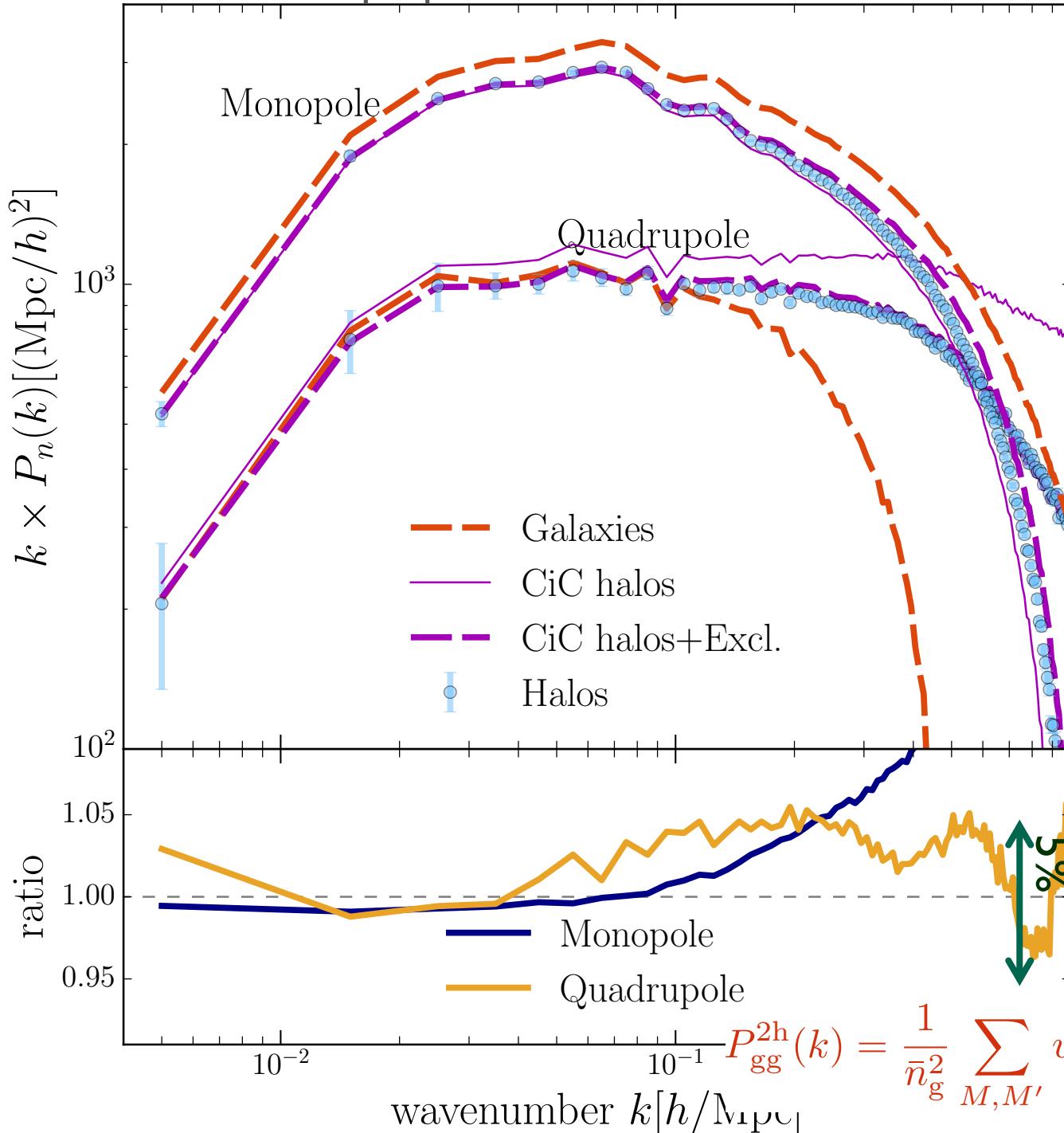
$$\hat{P}_{\text{hh}}(\mathbf{k}) = \frac{P_{hh}^{\text{CiC}}(\mathbf{k}) - W_{\text{CiC}}(\mathbf{k}) - [W_{\text{CiC}} * P_{\text{hh}}](\mathbf{k})}{\text{exclusion effect}} + \frac{\alpha(\mu^2)P_m^L(k)}{\text{apparent RSD}}$$

Here

$$W_{\text{CiC}}(k, \mu) = 2 \frac{J_1(k_\perp r_\perp^{\text{CiC}})}{k_\perp r_\perp^{\text{CiC}}} \frac{\sin(k_\parallel L_{\text{CiC}})}{k_\parallel L_{\text{CiC}}} V_{\text{CiC}}$$

$$\alpha(\mu) = a + b\mu^2$$

$a$  and  $b$  are free parameters



Teppei Okumura (IPMU)

- Systematic effects are now gone
- The quadrupole power spectrum shows a nice agreement at  $\sim 5\%$  level, up to  $k \sim 1 h/\text{Mpc}$
- No 1-halo term
- Note: FoG (off-centering effects)

# summary

- SuMIRe: Hyper Suprime-Cam (HSC; 2014-) + Prime Focus Spectrograph (PFS; 2019-)
- Weak lensing + Galaxy clustering to recover the halo distribution, by protecting against the galaxy bias uncertainty
- Use the 2-halo term, which is less sensitive to satellite galaxies as well as selection function of galaxies, for cosmology